



U.S. Army Benet Laboratories

Hard Chrome Alternatives Team 20-21 July, 2004, Utah



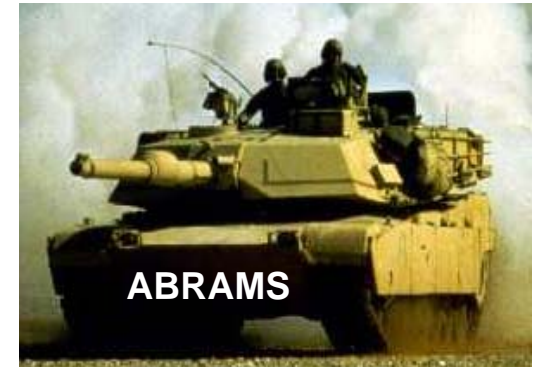
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Elimination of Chromium Electrodeposition from Large Caliber Launch Systems



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US Army Benet Laboratories

*part of the US Army Armaments Research, Development
and Engineering Center*



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LARGE CALIBER GUN EROSION

Direct Fire

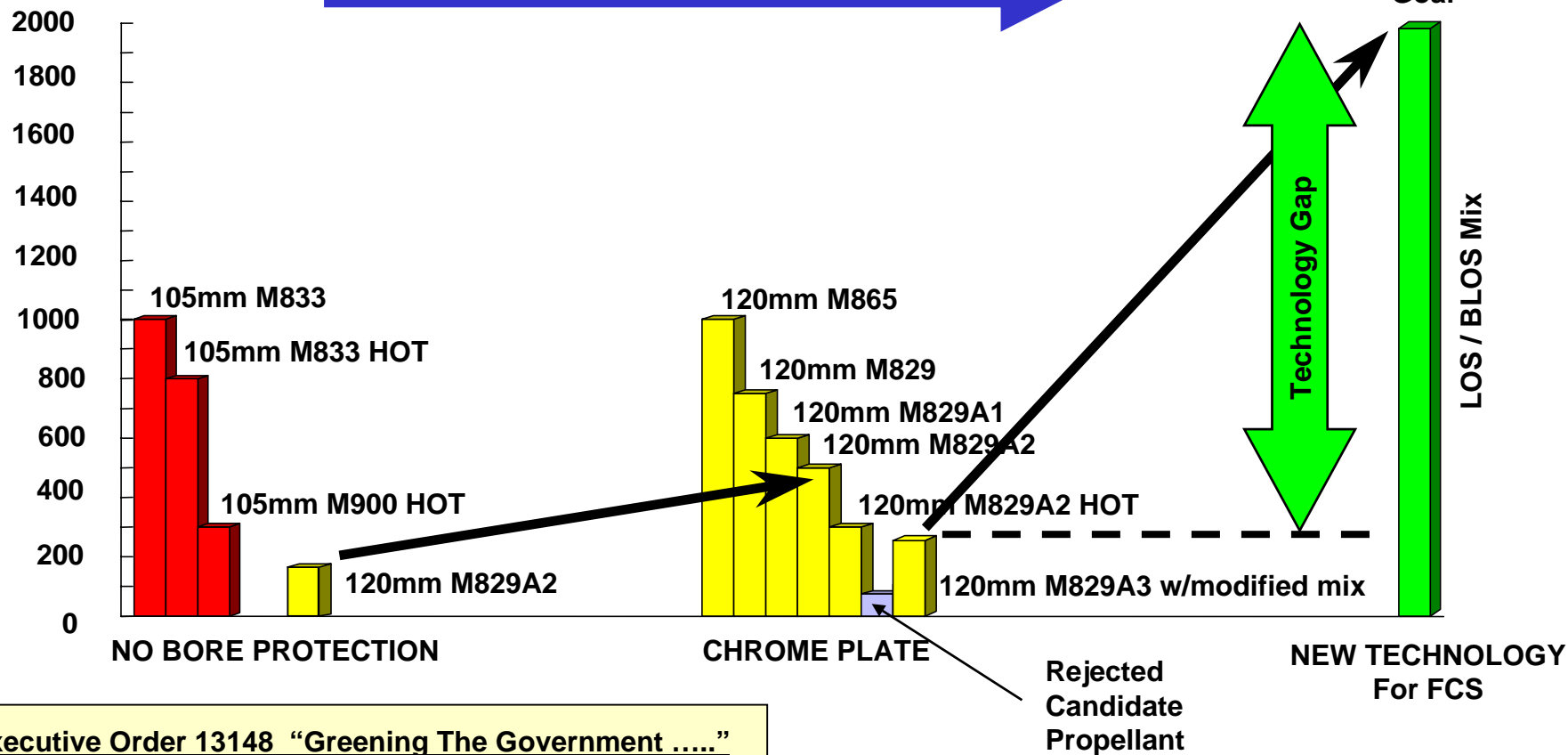


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BARREL
CONDEMNATION
(RNDs)

*INCREASING MUZZLE ENERGIES REQUIRE:
Improved Bore Protection
Less Erosive Energetics*



Executive Order 13148 "Greening The Government"

Reduction of Toxic Chemical Releases by 40% by 31 Dec 2006

Reduction of Toxic Chemical Usage by 50% by 31 Dec 2006



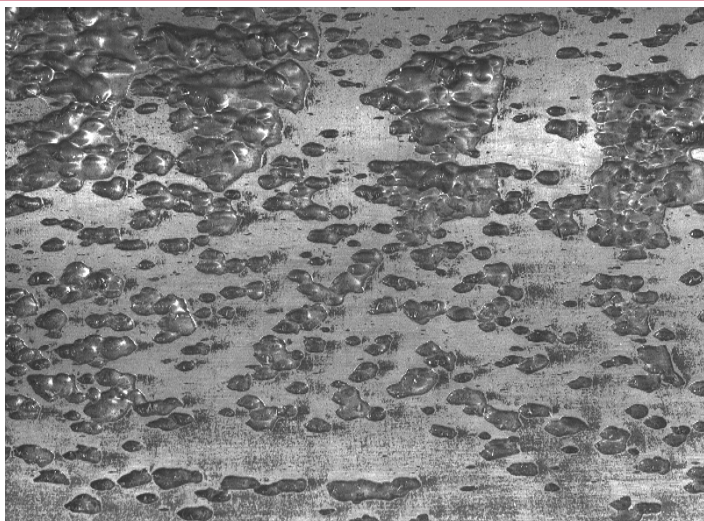
120mm GUN BARREL DEGRADATION

Classic Erosion Defined

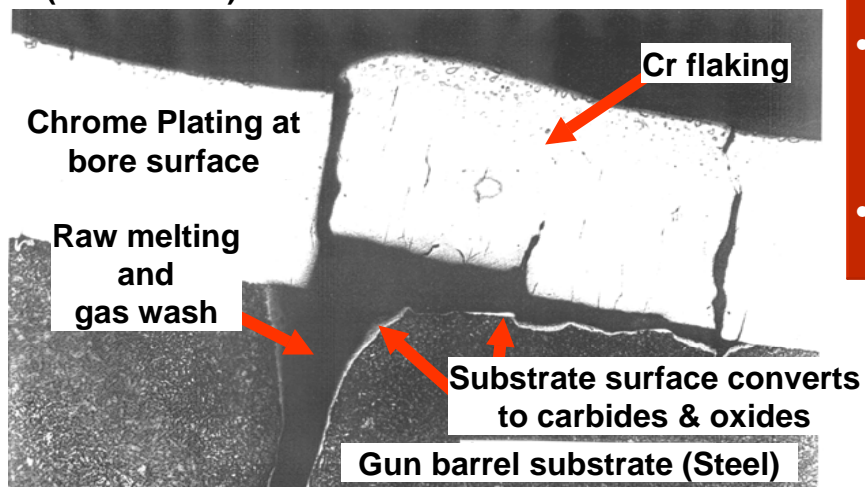


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Condemned ABRAMS 120mm GUN BARREL
(214 rounds) : **> 5mm erosion**



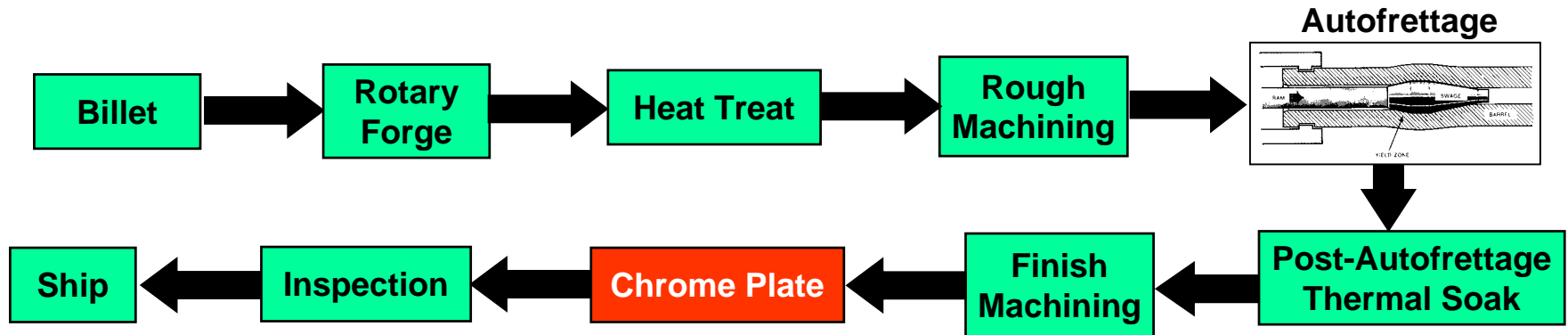
- HC Chrome is produced in an “as cracked” condition offering path to substrate
- HC Cr contaminants off-gas causing further material volume shrinkage and stress-relief cracking
- Combustion products:
 - Penetrate cracks
 - Alter steel substrate phase
 - Convert substrate surface to carbides & oxides
 - Lowers MP of substrate surface
- Gas wash:
 - Removes lower MP substrate surface
 - Erodes Cr foundation (compromised adherence)
- Departing Cr exposes more substrate to high velocity gas wash and further erosion



120mm GUN BARREL MANUFACTURING PROCESS



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Rotary Forging



Machining



Chrome Plating



Fielding



LARGE CALIBER GUN COATING REQUIREMENTS



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Material & Deposition Process Requirements

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MATERIAL CHARACTERISTIC

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Melting Point

Cr (1875 C) or better

Elastic Modulus

Compatible with substrate (facilitates low surface crack densities)

YS at Elevated Temps

High

Fracture Toughness

High

Hot Hardness

High (appropriate)

Chemical Resistance

High

Coefficient of Thermal Exp.

Compatible with substrate

Thermal Conductivity

Low

Reaction w/ Rotating Band

Inert

Phase Transformations

None

PROCESS CHARACTERISTIC

CRITERIA

Deposition Temperature

Less than 357C (post autofrettage thermal soak limit)

Deposit Rate

1 mil of coating material per hour

Surface Finish

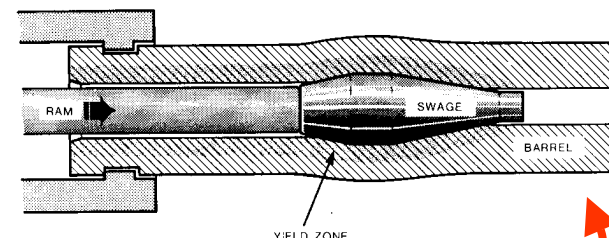
Equal or better than 32 RMS at deposition

Deposition Length

58 Calibers or greater

Hazardous Impacts

None or limited





COATING DEPOSITION PROCESS SELECTION

for Large Caliber Guns



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FUNCTIONAL REQUIREMENTS	PROCESS								
	Molten Salt	Plasma Spray	Chem. Vapor Dep.	Ion Implant.	Ion Plate	Explosive Bonding	Metal liding	Aqueous Electro-Dep	Cyl Magnetron Sputtering
				✓	✓			✓	✓
	✓			✓		✓	✓	✓	✓
	✓	✓	✓			✓		✓	✓
			✓					✓	✓
								✓	✓
	✓					✓		✓	✓
		✓	✓	✓	✓	✓	✓		✓
				✓	✓	✓			✓
				✓	✓	✓		✓	

•TECHNICAL PANEL EXPERTS (1997)



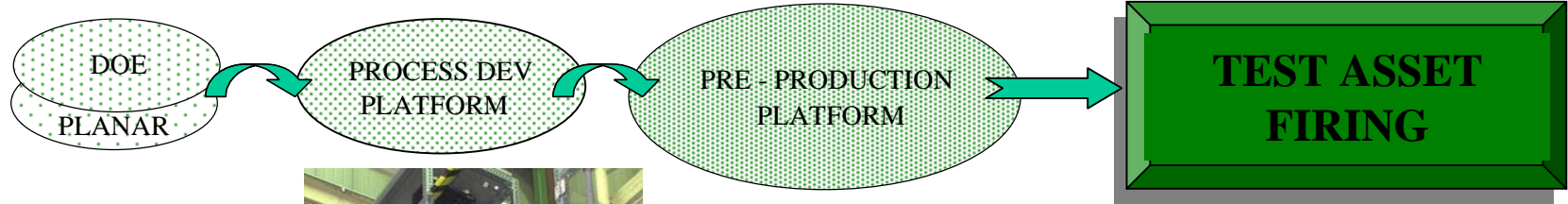
TECHNICAL APPROACH

Technology Maturation Methodology

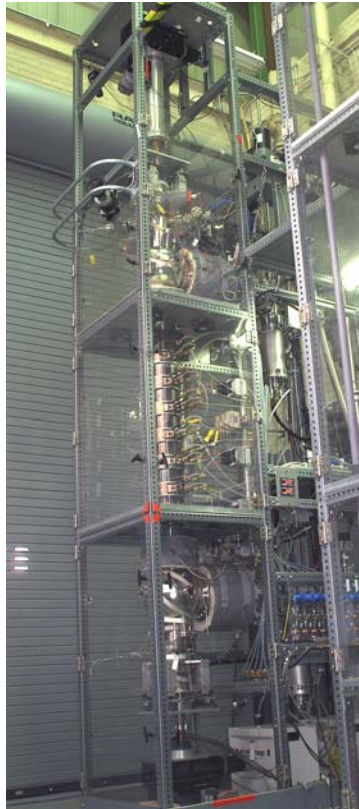


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Coupons &
12" Sections



40" Sections



Full-Length Gun Barrels



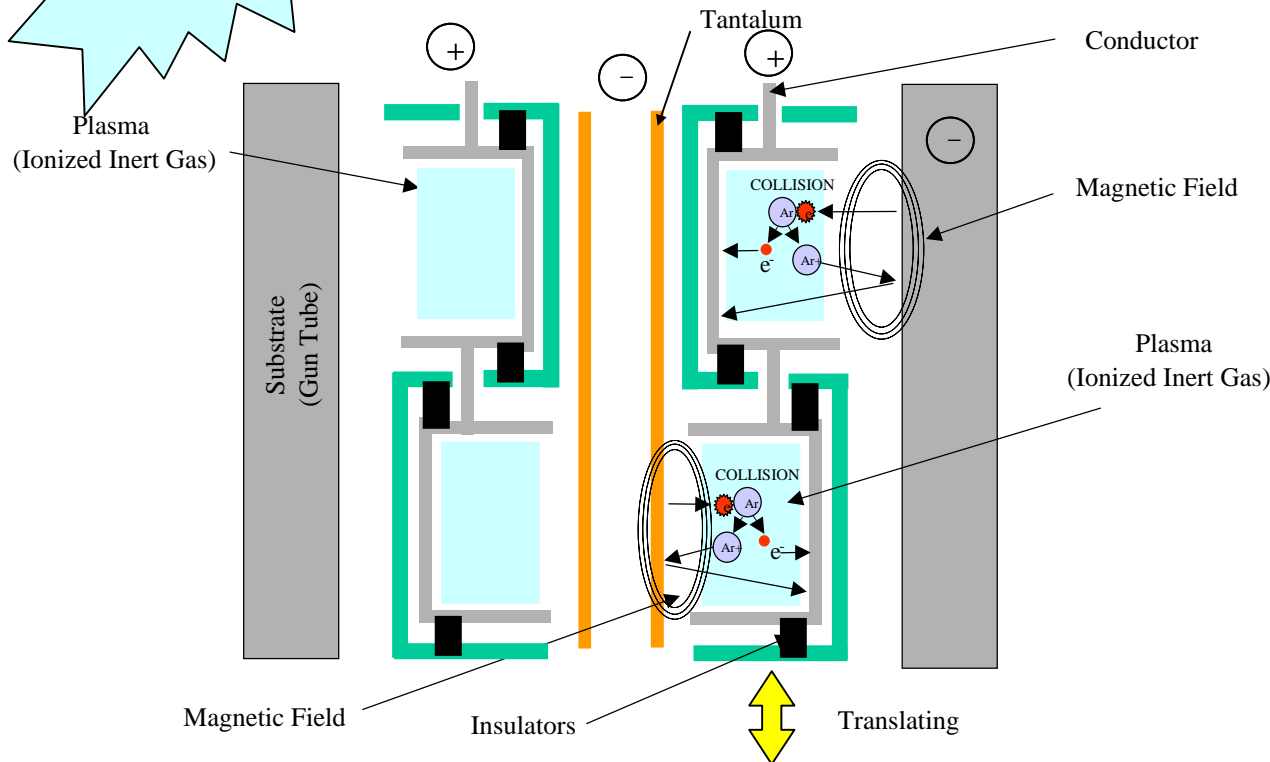
BENET SIGNIFICANT ACCOMPLISHMENTS

Lg Cal Plasma Cleaning Device (PCD)

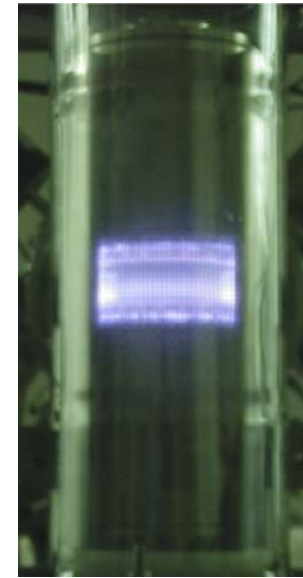
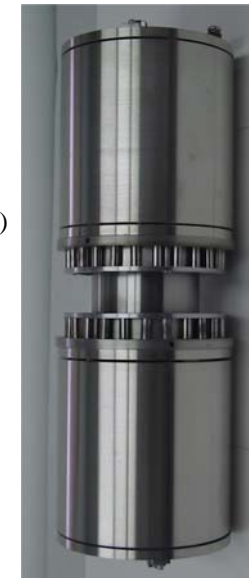


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ATOMICALLY
CLEAN
SURFACES

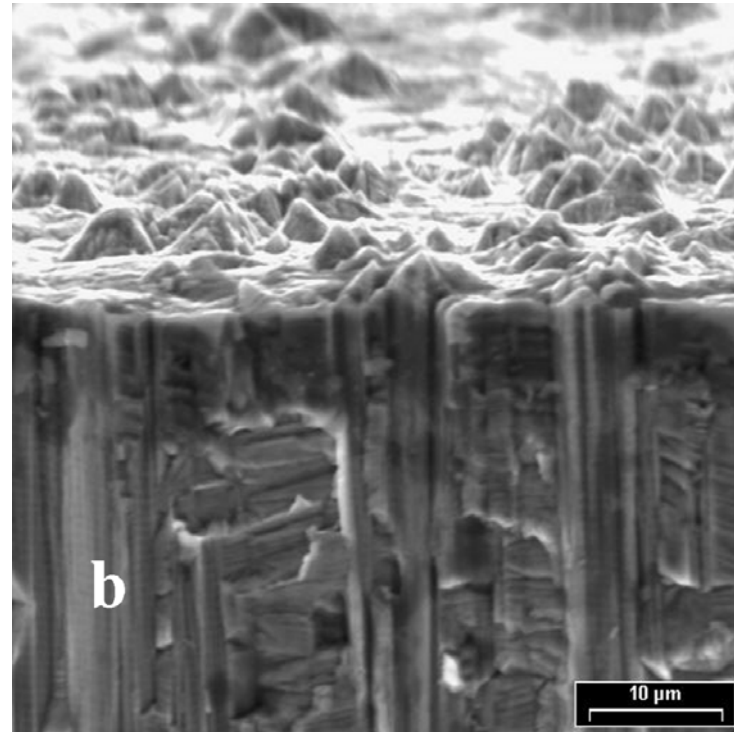
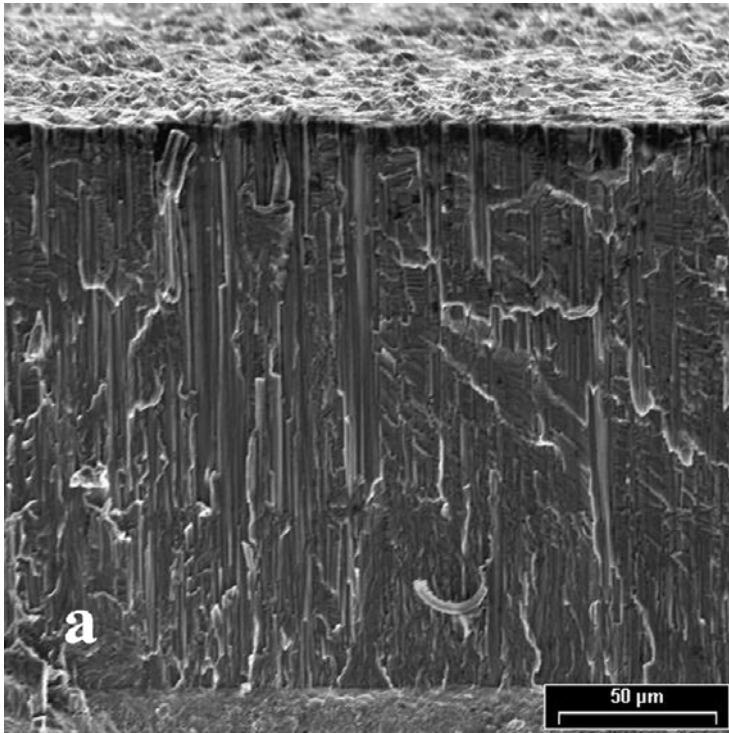


ARMY PATENT PENDING
Disclosure No. 2002-020



Lg Cal PCD Substrate Cleaning
w/PCD

An Army patent pending manufacturing technology to provide “atomically clean” surfaces for CMS deposition onto full length gun barrels

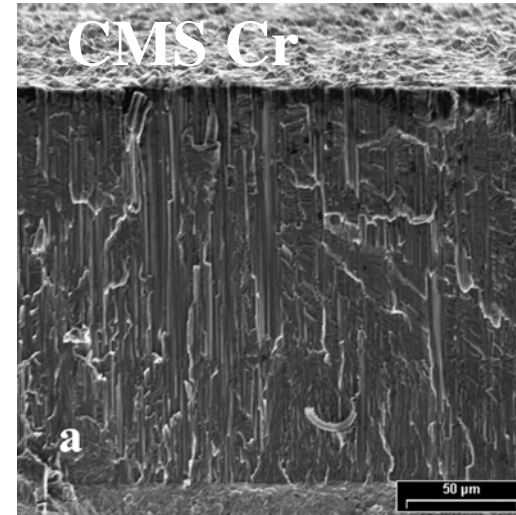
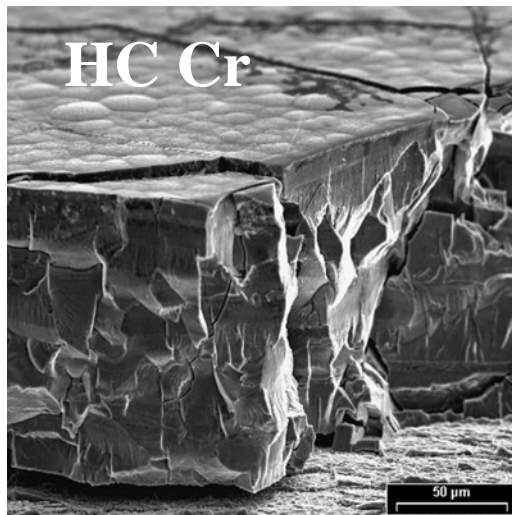
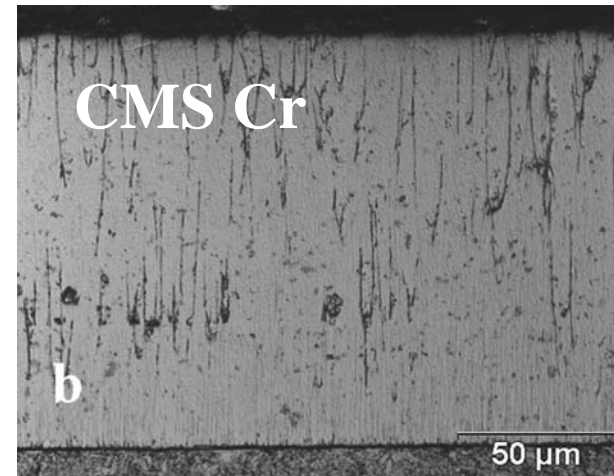
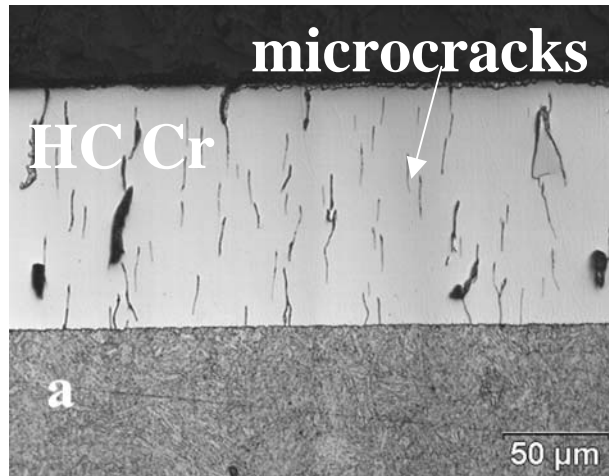


- SEM images of tensile fractured chromium specimens:
 - a: dense fibrous grain structure (zone T per Thornton)
 - b: small amount of columnar growths
- XRD residual stress study: compressive stress of ~ 30 Ksi

Cr Coating Comparison

Electroplated vs sputtered

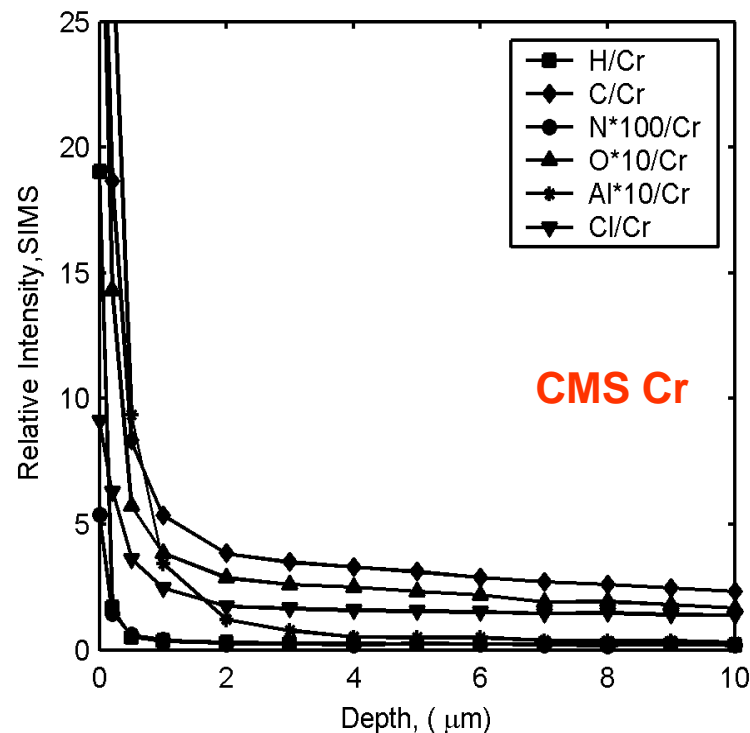
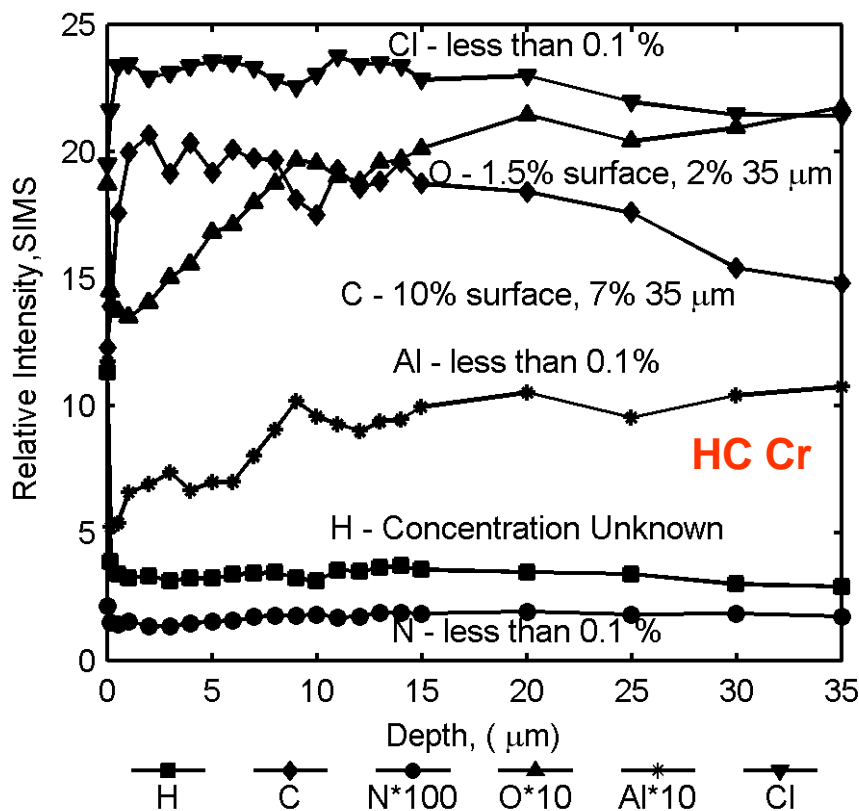
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Microhardness: HC Cr
CMS Cr

800-1000 HK
220 - 400 HK

Cr Coating Composition



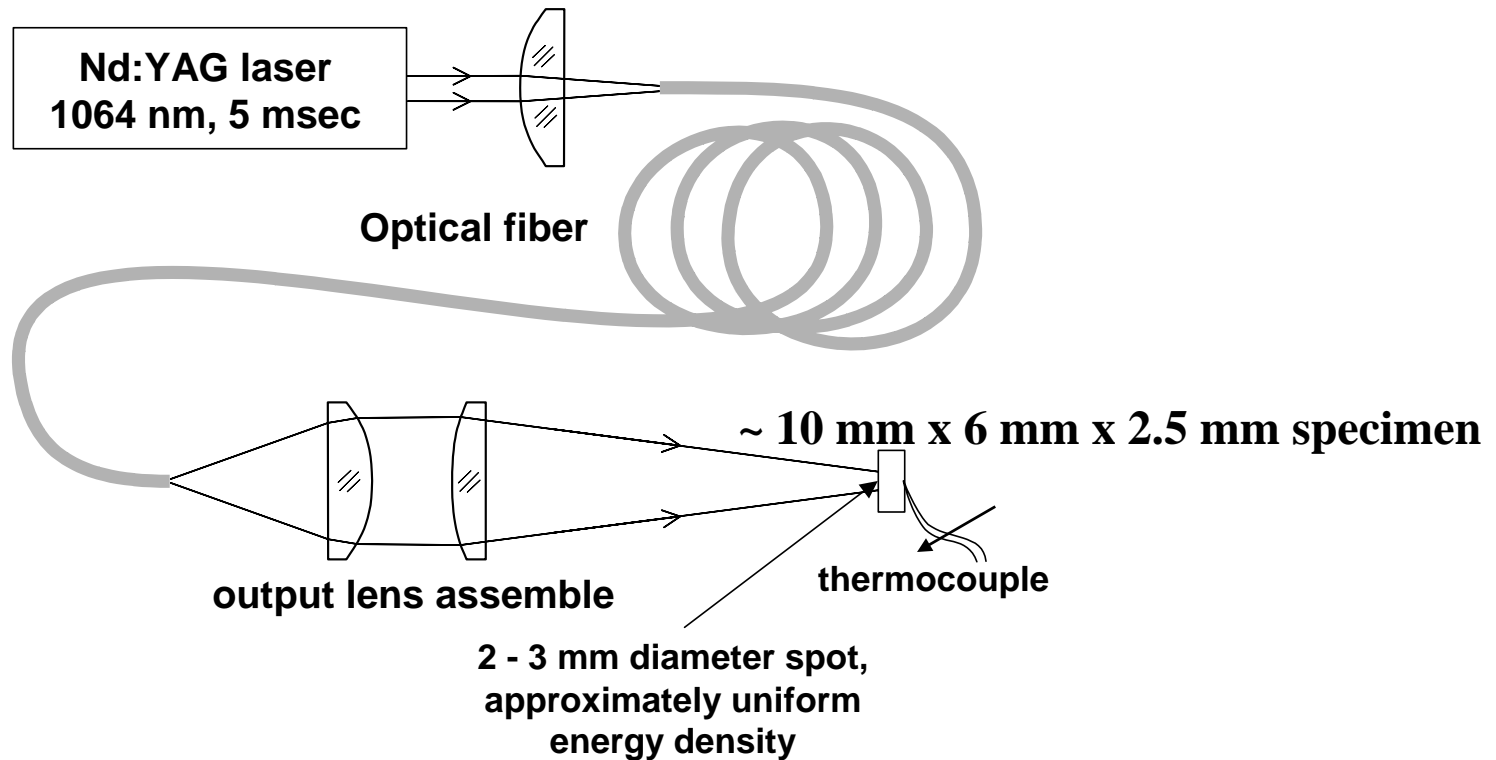
SIMS peak intensity vs profile depth

Bulk impurity concentration:

- CMS Cr: all non-Cr elements < 0.1at %
- HC Cr: carbon concentration ~ 10 at %, oxygen concentration ~ 2 at %

Laser Pulse Heating (LPH) method

Thermal shock resistance





Coating Evaluation Process Cont.

Adhesion and Erosion Rate



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NOVEL SPIN-OFF
TECHNOLOGY

Abrams M1A2 Main Battle Tank



Vented Erosion Simulator (VES): *For Interim Coatings Validation*

- Flame T & chemistry similar to M829A2/M829A3
- Accepts Lg Cal coated coupons
- Extensively modeled
- Does not exceed critical T observed in current gun barrel erosion process
- Used to screen, evaluate, optimize, and validate Lg Cal gun bore coatings



Benet's VES evaluates coatings in a simulated
Lg Cal Gun Firing Environment



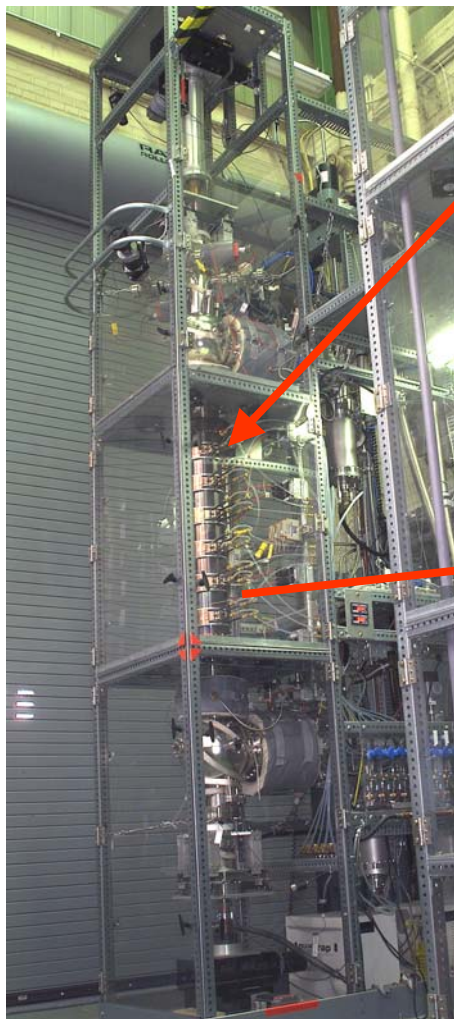
INTERIM COATINGS VALIDATION

Vented Erosion Simulator (VES) Testing

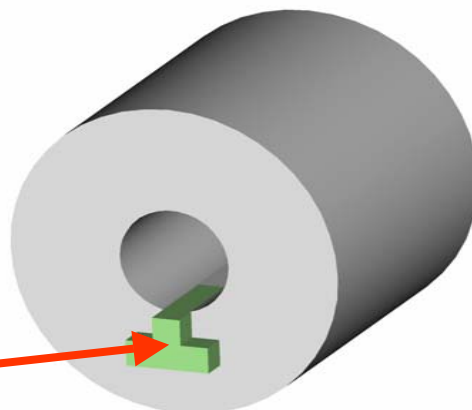


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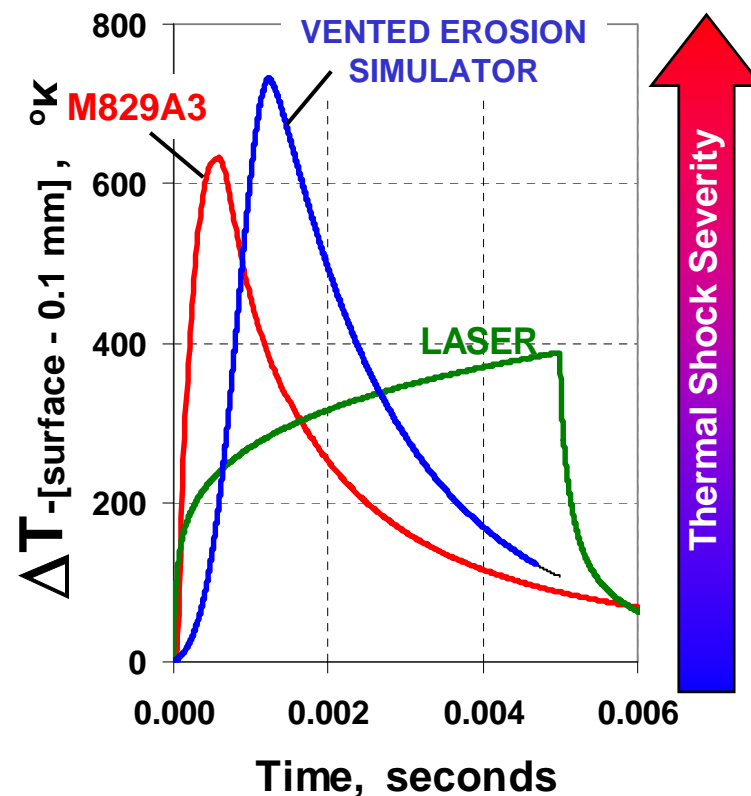
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Large Caliber
Gun Section



Vented Erosion
Simulator (VES)



- Flame T & chemistry similar to M829A2/M829A3
- Accepts Large Caliber coated coupons (*eliminates process scaling*)
- Ballistically modeled & validated
- Substrate transformed to same depth as Lg Cal Gun
- Maintains critical T observed in current gun barrel erosion process



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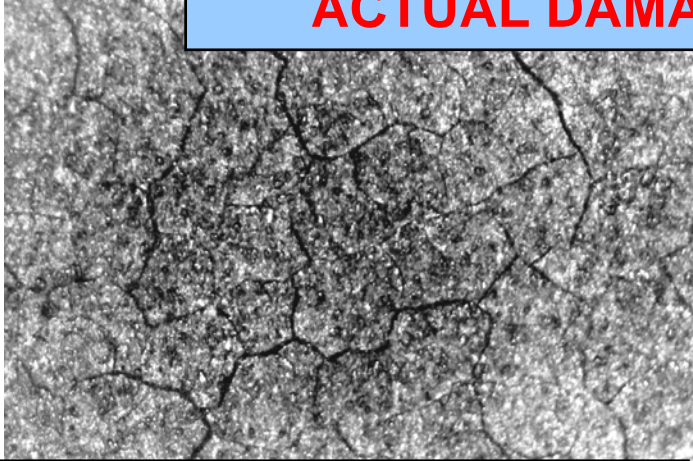
VENTED EROSION SIMULATOR (VES)

an excellent simulation of Lg Cal gun firing

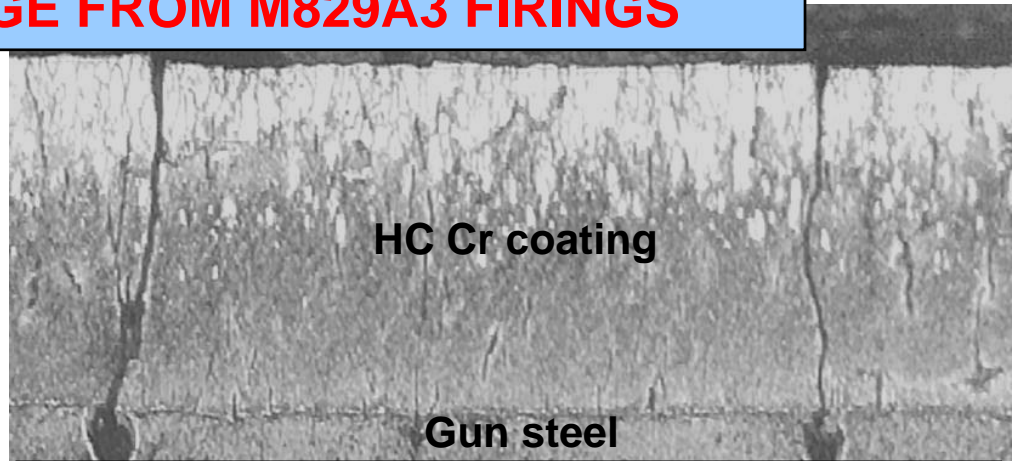


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ACTUAL DAMAGE FROM M829A3 FIRINGS

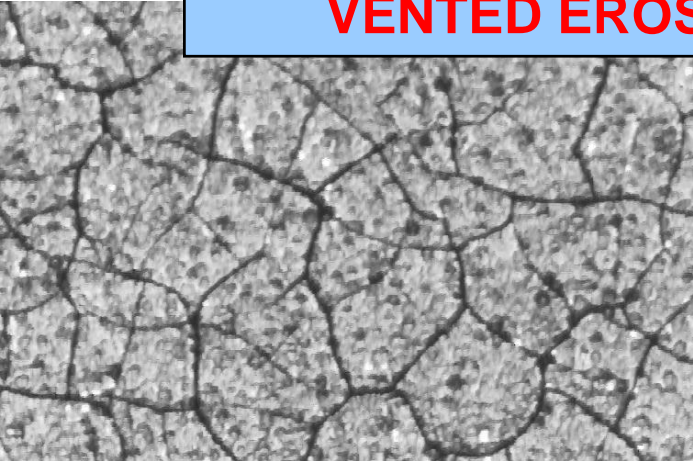


Top View – Thermal shock cracking

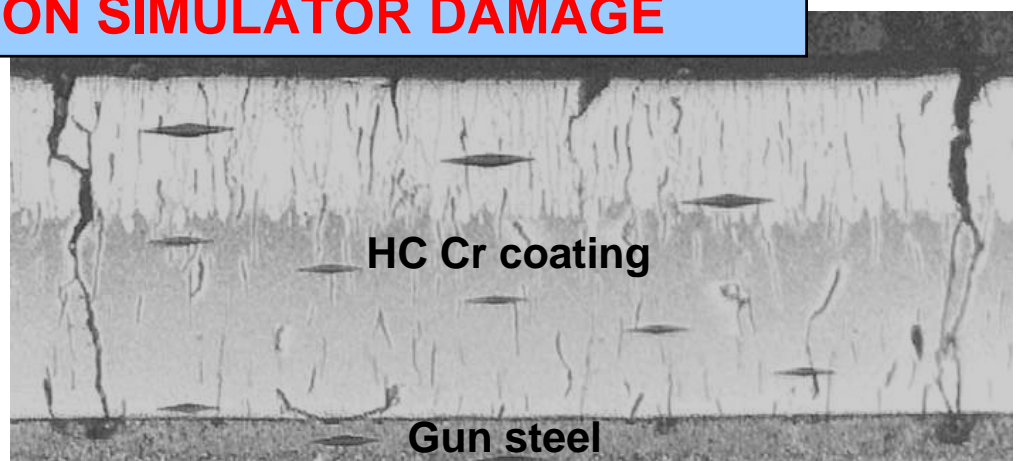


X-Section – Cracking, HAZ, thermo-chemical attack

VENTED EROSION SIMULATOR DAMAGE



Top View – Thermal shock cracking



X-Section – Cracking, HAZ, thermo-chemical attack



COATING CRACK DENSITY

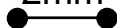
Substrate Exposure – Erosion Rate



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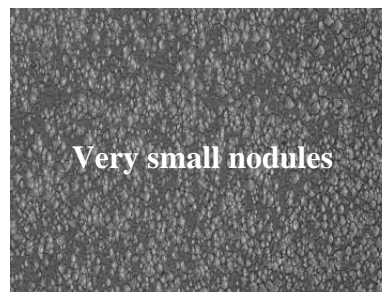
As-Deposited
Surface Appearance

2mm


HC Cr



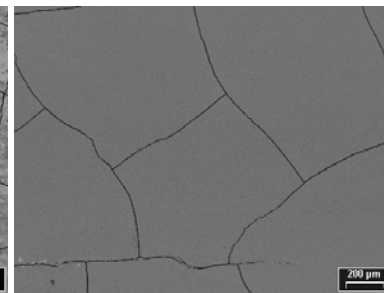
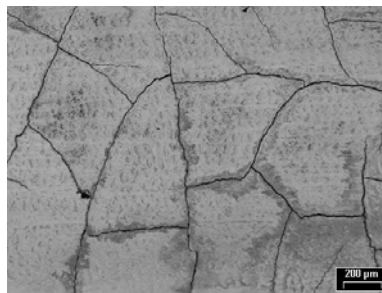
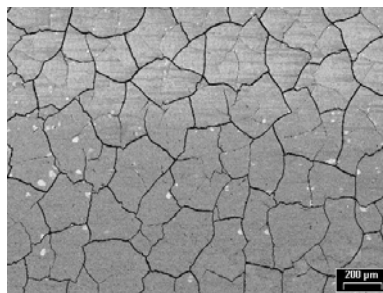
Sputtered Cr



Sputtered Ta



Post-firing
Crack Island Size
(aka Crack Density)



Substrate Exposure

Erosion Life

120mm Tank Gun Surfaces



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Summary of TECHNICAL METRICS

Advanced Coatings for Large Caliber Guns



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CHARACTERISTIC	Current state of HC CHROME PLATING	Desired end state for SPUTTERING	VERIFICATION TECHNIQUE	CURRENT STATUS
Coating Morphology	Zone 2	Zone 2	Microscopy	yes
Coating Phase	Single	100% Alpha (Ta) bcc (Cr)	Microscopy Microscopy	yes yes
Hardness	900 -1100 Knoop	200 - 300 Knoop	Microhardness (Ta) Microhardness (Cr)	yes yes
Thermal Shock Resistance	Poor	Excellent	Pulsed Laser Vented Erosion Sim	yes yes
Adhesion / Cohesion	Excellent	Excellent	Groove Testing VES (Ta) VES (Cr)	yes yes yes
Distribution over Length	.002 - .006 in.	Less than .0005	Microscopy	yes (80")
Distribution around ID	.002 - .006 in.	Less than .0005	Microscopy	yes
Deposition Rate	.001 inches/hr	.001 inches/hr	Microscopy	no (.00075)
Coating Thickness	.002 - .006 in.	.004 - .006 in.	Microscopy	yes
Surface Finish	63 finish	32 or better	Visual	yes (16)
Onset of Erosion	100 VES shots	better	Visual / Microscopy	yes
Weapon Service Erosion Life	260 Rnds (M829A3)	400 Rnds (M829A3)	Firing Tests	TBD



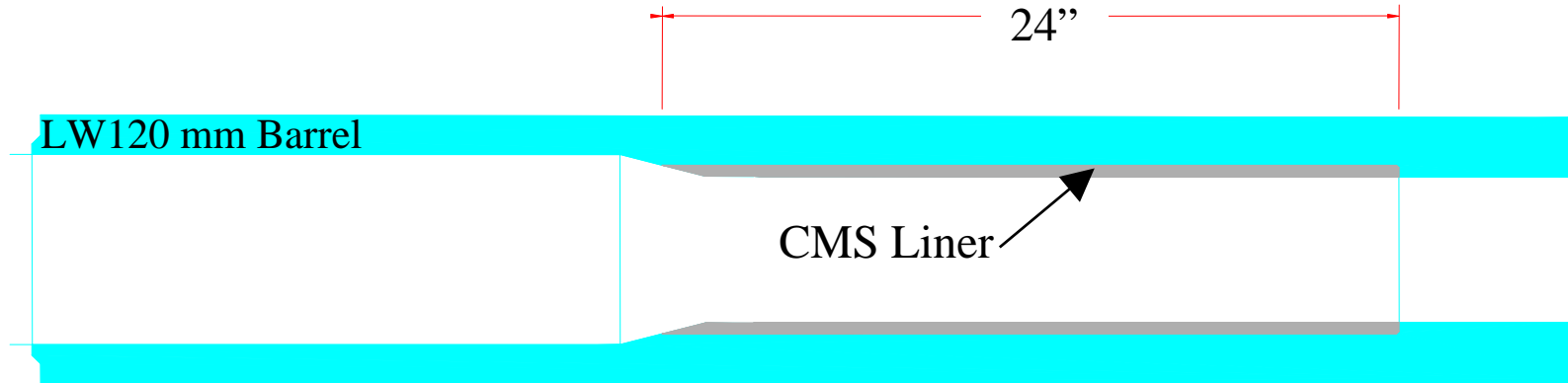
UPCOMING FIRING DEMONSTRATIONS

Advanced Sputtered Coatings



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120mm XM36 Firing Test #1

- 120mm coated, shrink-fit liner
- July 04

120mm XM36 Firing Test #2

- 120mm coated, shrink-fit liner
- Oct-Nov 04

120mm XM36 Sub-Scale Development & Testing

- Full-length monoblock coating test
- Mid FY05



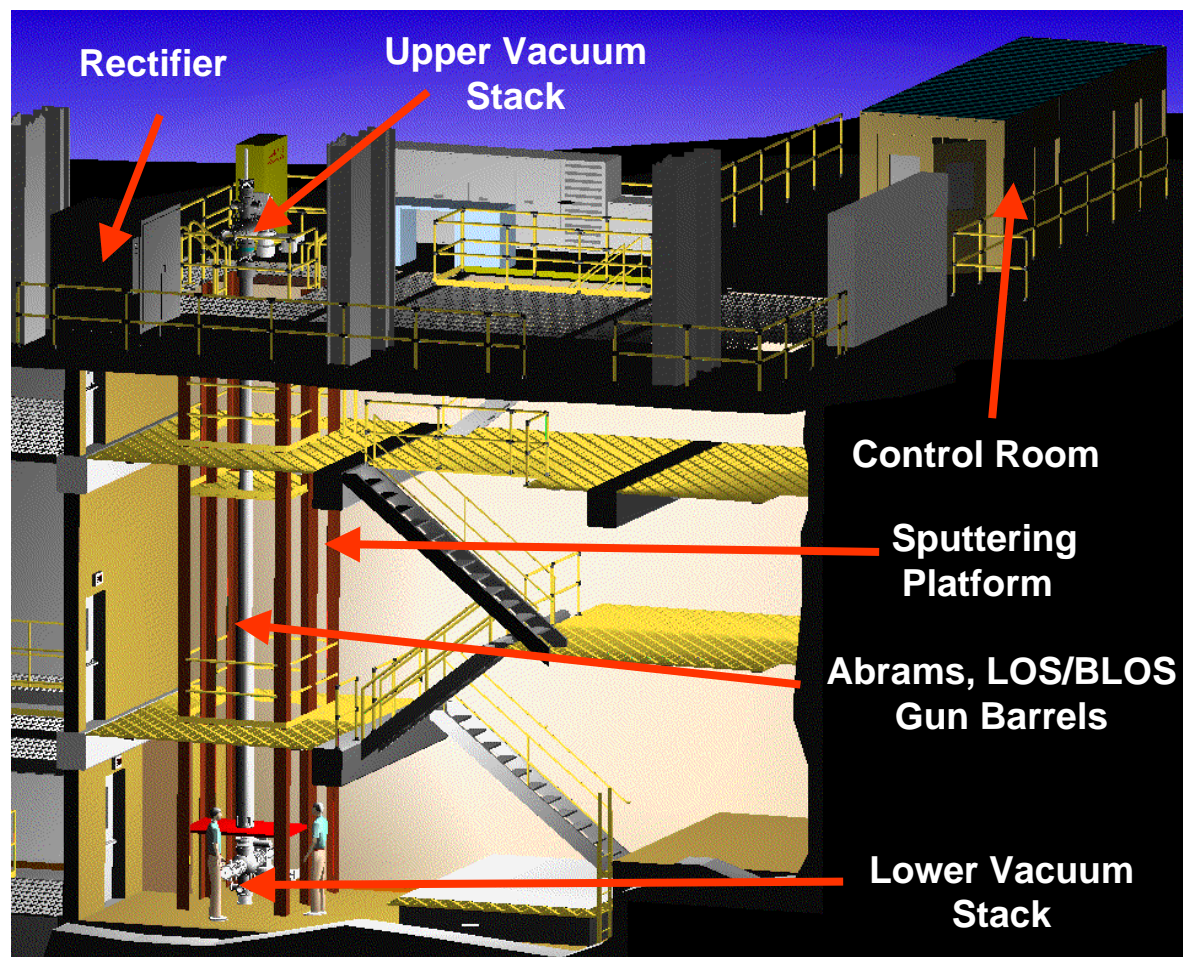


LARGE CALIBER Pre-PRODUCTION Demonstration Platform



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U.S. Army Benet Laboratories *at Watervliet Arsenal – Initial Testing - Sep 04*





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SUMMARY



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- **Cylindrical Magnetron Sputtering is a viable alternative to electrodeposition**
- **Cylindrical Magnetron Sputtering results encouraging for large caliber systems**
 - Increased adhesion and bulk properties
 - All laboratory metrics achieved (*still improving deposition rate*)
- **Current 120mm XM36 tests should be insightful**
- **Large Caliber Full-length Pre-Production Platform Initial Testing by Sep 2004**
- **Will one coating technology address all platforms ???**
 - Large Cal vs. Med Cal
 - Autofrettaged vs. Non-Autofrettaged
 - Smoothbore vs. Rifled bore